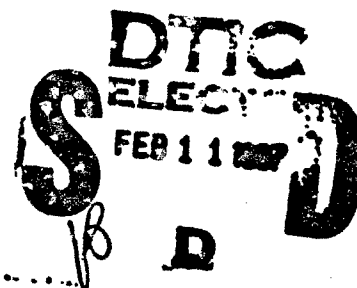


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Monterey, California



THESIS

AN UNDERWATER SEAWATER BATTERY MONITOR  
AND TELEMETRY RECORDING SYSTEM

by

Elton Ray Gibson, Jr.

December 1986

Thesis Advisor:

John P. Powers

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**An Underwater Seawater Battery Monitor  
and Telemetry Recording System**

by

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Lieutenant Commander, United States Navy  
B.S.M.E., Auburn University, 1977**

**Submitted in partial fulfillment of the  
requirements for the degree of**

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3

# ABSTRACT

This thesis presents the design, test, and evaluation of a system developed to remotely monitor and record telemetry data from a one volt seawater battery. The monitoring system provides the ability to monitor telemetry information from a battery located up to one kilometer from a shore based data recorder. The system consists of a voltage-to-frequency converter which converts the voltage of the battery to a digital signal, the optical transmitter, the fiber optic receiver, a frequency-to-voltage converter which converts the digital signal to an output voltage and a programmable periodic data recording system. The system was deployed and successfully tested in a seawater environment.

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## TABLE OF CONTENTS

I.	INTRODUCTION . . . . .	8
II.	SYSTEM DESIGN . . . . .	11
	A. VOLTAGE TO FREQUENCY CONVERTER (V/F CONVERTER) . . . . .	11
	B. FIBER OPTIC DATA LINK . . . . .	14
	1. Transmitter. . . . .	19
	2. Receiver . . . . .	23
	C. FREQUENCY TO VOLTAGE CONVERTER (F/V CONVERTER) . . . . .	24
	D. POWER SUPPLIES . . . . .	27
	E. DATA RECORDING SYSTEM. . . . .	29
	1. HP-85 Microcomputer. . . . .	30
	2. HP 3490A Multimeter. . . . .	30
	3. HP 7470A Graphics Plotter. . . . .	32
	4. Data Recording Programs. . . . .	32
	F. ENVIRONMENTAL ENCLOSURES . . . . .	34
III.	TEST AND EVALUATION. . . . .	37
IV.	CONCLUSIONS AND RECOMMENDATIONS. . . . .	46
APPENDIX A	CONSTANT CHARGING PROCEDURE . . . . .	48
APPENDIX B	PROGRAM CODES . . . . .	50
APPENDIX C	CONTROLLER PROGRAM . . . . .	51
APPENDIX D	TAPE TO FLOPPY DISK CONVERSION PROGRAM . . . . .	54

LIST OF REFERENCES. . . . . 55

INITIAL DISTRIBUTION LIST . . . . . 57

## LIST OF TABLES

2.1	Fiber Optic Cable Specifications . . . . .	15
2.2	Transmitter Parameters . . . . .	17
2.3	Receiver Parameters . . . . .	18
2.4	Estimated Battery Life . . . . .	29

## LIST OF FIGURES

1.1	System Concept . . . . .	9
2.1	V/F Converter . . . . .	12
2.2	V/F Converter Linearity Test . . . . .	13
2.3	Transmitter Drive Circuit . . . . .	21
2.4	Transmitter Output vs. Forward Current . . . . .	22
2.5	Receiver Drive Circuit . . . . .	25
2.6	F/V Converter . . . . .	26
2.7	Data Recording System . . . . .	31
2.8a	Transmitter Enclosure . . . . .	36
2.8b	Power Supply Enclosure . . . . .	36
2.9	Data Link Circuit . . . . .	38
2.10	Voltage Divider Circuit . . . . .	39
2.11	9 Volt Alkaline Battery Degeneration Characteristics . . . . .	41
2.12	9 Volt Lead Acid Battery Degeneration Characteristics . . . . .	42
2.13	12 Volt Nickel-Cadmium Battery Degeneration Characteristics . . . . .	43
2.14	Deployed System . . . . .	44
2.15	System "Wet Test" Results (6 Volt Nickel-Cadmium Battery Degeneration Characteristics . . . . .	45
A.1	Constant Current Charging . . . . .	49

## I. INTRODUCTION

The requirement exists to provide an effective means to monitor telemetry information from a one volt, one ampere, long-life seawater battery submerged in a deep ocean environment. This thesis is a continuation of efforts to design, develop, deploy and test a fiber optic data link to transmit seawater battery telemetry information to a shore based programmable recording system.

The recent increased use of fiber optics in data communication systems has resulted in an increase in efficiency and availability and a decrease in cost of data link elements. The improved performance of transmitters and receivers makes fiber optic data links in excess of one kilometer, without the requirement for data repeaters, possible. Incorporation of data repeaters in the optic data link to improve transmission distances is beyond the scope of this thesis.

The system concept is illustrated in Figure 1.1. Chapter two presents a detailed analysis of the system design. Each element of the system as presented in Figure 1.1 is discussed individually.

The system was developed around the requirement to use approximately one kilometer of available 50/125  $\mu\text{m}$  fiber optic cable. System development included component

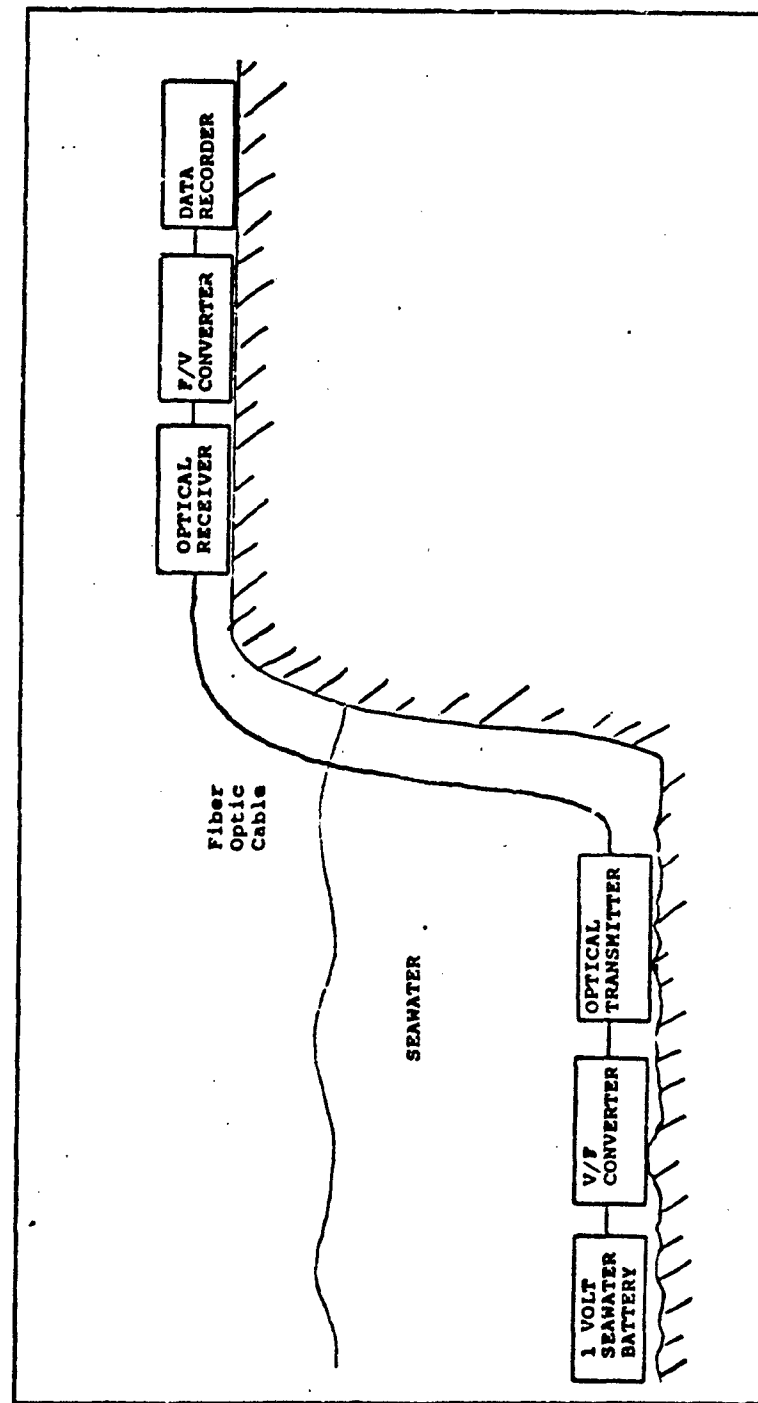


Figure 1.1 System Concept

selection, circuit design and implementation, hardware integration, recording system software development and integrated test and evaluation. Final analysis indicates that the seawater battery monitoring system as developed and tested provides an effective means to remotely monitor and record seawater battery telemetry.

## II. SYSTEM DESIGN

### A. VOLTAGE TO FREQUENCY CONVERTER (V/F CONVERTER)

Since commercially available fiber optic data link components are optimized for digital transmission, the analog voltage was first converted to a digital TTL signal. Koo [Ref. 1] tested and evaluated a circuit suitable for accomplishing this task. A similar circuit was constructed and is shown in Figure 2.1. As implemented, the V/F converter will convert a dc voltage ranging from 0.1 to 1 volt to a corresponding TTL signal of 1 to 10 KHz. The linearity of the circuit was tested and can be seen from Figure 2.2.

The LM331 voltage-to-frequency converter circuit [Ref. 2] is capable of converting a 1 to 10 volt dc signal to a 1 to 10 KHz TTL signal. But, the battery monitor was ultimately to be used to monitor the voltage of a one volt seawater battery for the lifetime of the battery. In order to make use the LM331 voltage-to-frequency circuit, the seawater battery voltage was first amplified by a factor of ten using a LM124J operational amplifier. Thus over the life of the 1 volt seawater battery, the amplifier provides the desired analog signal to the LM331 voltage-to-frequency converter. The effect of prescaling  $V_{in}$  was accounted for

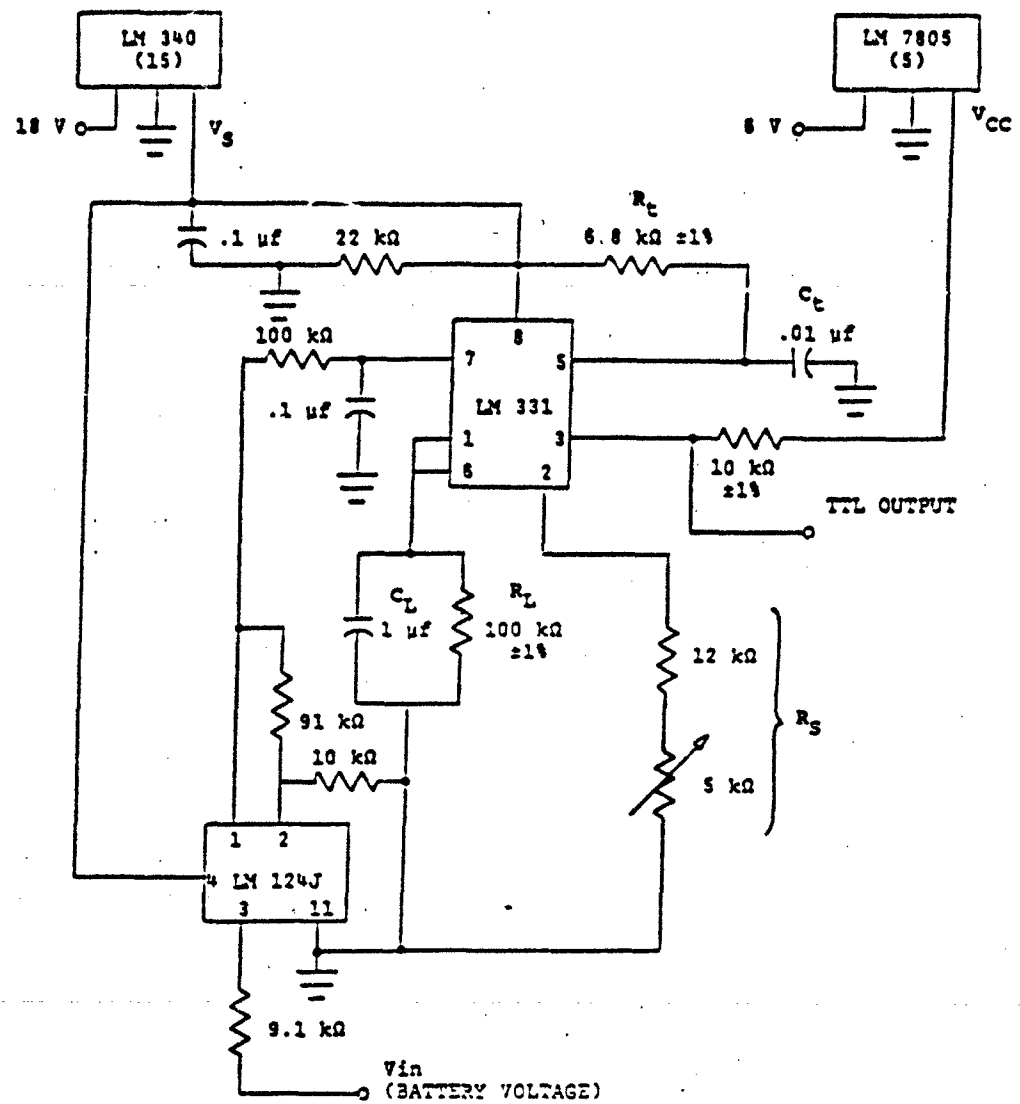


Figure 2.1 V/F Converter

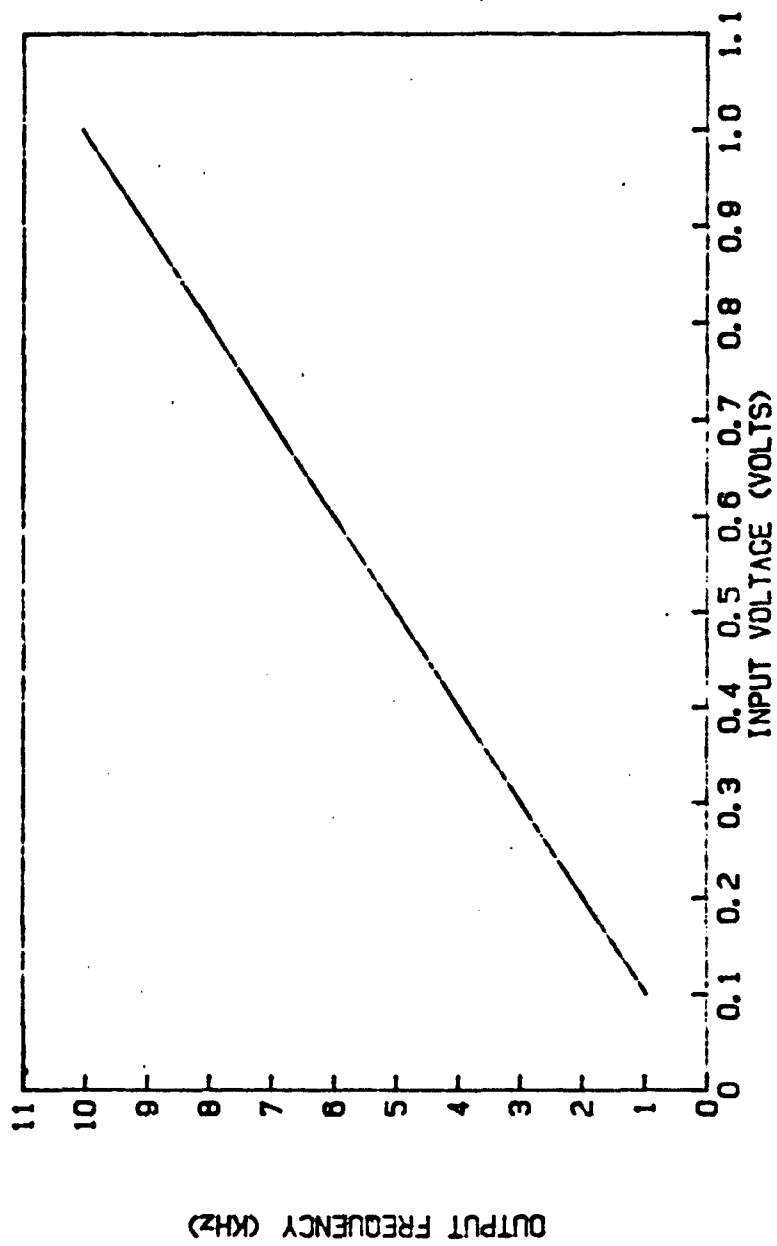


Figure 2.2 V/F Converter Linearity Test

in the data recording routine and is discussed in further detail later in this chapter.

The frequency of the TTL output,  $f_{out}$ , from the V/F converter is related to the seawater battery voltage,  $V_{in}$ , by:

$$f_{out} = 10 V_{in} R_S / 2.09 V_S R_L R_t C_t \quad (2.1)$$

The 5000 ohm potentiometer in Figure 2.1 enables the output frequency to be adjusted to a corresponding input voltage. For example, a 0.5 volt input should produce a TTL output of 5 KHz. Additionally, the 5000 ohm potentiometer provides the ability to "tune" the completed system to achieve a matched input-output response for a selected  $V_{in}$ .

In effect, the seawater battery voltage is prescaled by a factor of ten and then converted to a TTL signal varying from 10 to 1 KHz over the life of the battery. The TTL output from the V/F converter provides the input to the fiber optic transmitter.

#### B. FIBER OPTIC DATA LINK

The requirement that data be transmitted over one kilometer of fiber optic cable dictates the proper selection of the fiber optic data link transmitter and receiver for a specified fiber optic cable. Several design factors influenced data link design and operation. Fiber optic cable parameters, individual data link receiver and transmitter

performance characteristics, data transmission rates, and bit error rate were considered in the integral data link design and implementation.

The single constraint imposed on the design of the fiber optic data link was the fiber optic cable available. The cable available for testing and deploying the seawater battery monitoring system was a semirigid, fiberglass-jacketed, graded index fiber. Table 2.1 lists characteristics of the fiber optic cable.

TABLE 2.1

FIBER OPTIC CABLE SPECIFICATIONS

Fiber Size .....	50/125 $\mu$ m
Fiber Type .....	Graded Index
Fiber Length (L) .....	1094 m
Attenuation .....	3.7 dB/Km
Core Index of Refraction .....	1.475
Cable Outside Diameter .....	2.05 mm

Selection of the fiber optic transmitter and receiver was based on power requirements necessary to overcome inherent attenuation losses. Additionally, item cost and availability were considered in the selection of a suitable fiber optic receiver and transmitter. Tables 2.2 and 2.3 provide a list of fiber optic receivers and transmitters

that were considered in the data link design. Again, the dominating criteria in selecting the fiber optic transmitter was the requirement to launch sufficient power into the fiber to overcome the attenuation losses experienced due to fiber length and fiber optic cable connectors.

To determine which receiver-transmitter pair would provide sufficient power to overcome transmission losses, an analysis was made using transmitter power available to be coupled into the fiber,  $P_T$ , and the required receiver power,  $P_R$ . The acceptable losses,  $L_A$ , that may be incurred in the data link are given by:

$$L_A \text{ (dB)} = 10 \log (P_R/P_T) \quad (2.2)$$

The distribution of the acceptable losses is given by the following relationship:

$$L_A \text{ (dB)} = a_o L + l_T + n l_C + l_R + l_M \quad (2.3)$$

Where:

$a_o$  = Loss Per Kilometer (dB)

$L$  = Fiber Length (Km)

$l_T$  = Source To Fiber Coupling Loss (dB)

$l_C$  = Connector Insertion Loss (dB)

$l_R$  = Fiber To Receiver Loss (dB)

$l_M$  = System Margin (dB)

TABLE 2.2

## TRANSMITTER PARAMETERS

<u>TRANSMITTER</u>	<u>P<sub>T</sub></u>	<u>COST</u>
HFBR-1404	-17.5 dBm 17.7 $\mu$ w	35.00
HFBR-1202	-24.0 dBm 4.0 $\mu$ w	37.00
HFBR-1204	-19.2 dBm 12.0 $\mu$ w	88.00
HFBR-1402	-22.0 dBm 6.45 $\mu$ w	29.00
HFBR-1002	-21.0 dBm 7.9 $\mu$ w	260.00
Siecor V42253-G4-B2	-20.0 dBm 10.0 $\mu$ w	unk
Siecor V42253-G1-B2	-21.0 dBm 7.9 $\mu$ w	unk
Lecroy HLP-118	-17.0 dBm 18.0 $\mu$ w	unk

TABLE 2.3

## RECEIVER PARAMETERS

<u>TRANSMITTER</u>	<u>P<sub>T</sub></u>	<u>COST</u>
HFBR-2404	-21.5 dBm 7.0 $\mu$ W	20.00
HFBR-2202	-24.0 dBm 4.0 $\mu$ W	60.00
HFBR-2204	-21.5 dBm 7.0 $\mu$ W	33.00
HFBR-2402	-24.0 dBm 4.0 $\mu$ W	31.00
HFBR-2002	-27.9 dBm 1.6 $\mu$ W	unk
Siecor V42253-H4-B2	-35.0 dBm .316 $\mu$ W	unk
Siecor V42253-G2-B7	-31.0 dBm .79 $\mu$ W	unk
Lecroy HPL-118	-20.0 dBm 10.0 $\mu$ W	unk

Since the values for  $P_T$  were measured at the end of one meter of 50/125 micrometer fiber optic cable, losses  $l_T$  and  $l_R$  are already included and do not contribute to the calculation of the losses in Eq. 2.3 [Ref. 3]. Additionally, no in-line connectors were used. Therefore Eq. 2.3 can be rewritten as:

$$l_M = 10 \log (P_R/P_T) - a_o L \quad (2.4)$$

In order to achieve a successful data link, the system margin,  $l_M$ , must be positive. Based on component availability, cost and a computed system margin of 2.68 dB, the Hewlett-Packard HFBR-1404 transmitter and HFBR-2402 receiver were selected to develop the fiber optic data link.

Prior to acquiring the HFBR-1404 and HFBR-2402, other available transmitter and receiver pairs were implemented in hardware. These preliminary fiber optic data links were constructed to facilitate voltage-to-frequency and frequency-to-voltage circuitry testing. In each of the preliminary data links constructed, the system margin for the 1 Km link was negative and the data links were experimentally proven unsuccessful.

#### 1. HFBR-1404 Transmitter

The Hewlett-Packard HFBR-1404 Fiber Optic Transmitter is a high speed low cost transmitter that contains a planar 820 nm GaAlAs emitter which is optimized for small fiber and can typically launch -17.5 dbm (17.8  $\mu$ w) of

optical power into the 50/125  $\mu\text{m}$  fiber. The ability to launch relatively high levels of power into the fiber makes data transmission in excess of one kilometer possible. Additionally, the HFBR-1404 transmitter's high coupling efficiency allows the emitter to be driven at low current levels.

The HFBR-1404 transmitter is housed in a low cost dual-in-line package. As provided, the transmitter was suitable for use on a PROTO board during the breadboard phase of design and was subsequently soldered on a VECTOR board for final circuit integration.

Figure 2.3 is the transmitter drive circuit used for the HFBR-1404. The SN75451 Dual Peripheral Positive-AND Driver causes the transmitter LED to be pulsed at the same frequency as the TTL drive signal from the voltage-to-frequency converter.

The amount of power launched into the fiber optic cable,  $P_T$ , is function of the forward drive current,  $I_F$ . Figure 2.4 is a plot of  $P_T$  vs.  $I_F$ . The forward drive current,  $I_F$ , was obtained from the following relationship:

$$I_F = 0.1 V_T \quad (2.5)$$

The values of  $P_T$  were experimentally measured at the end of one meter of 50/125  $\mu\text{m}$  cable using a PHOTODYNE Optical Waveform Analyzer (Model 1600XP). The voltage drop

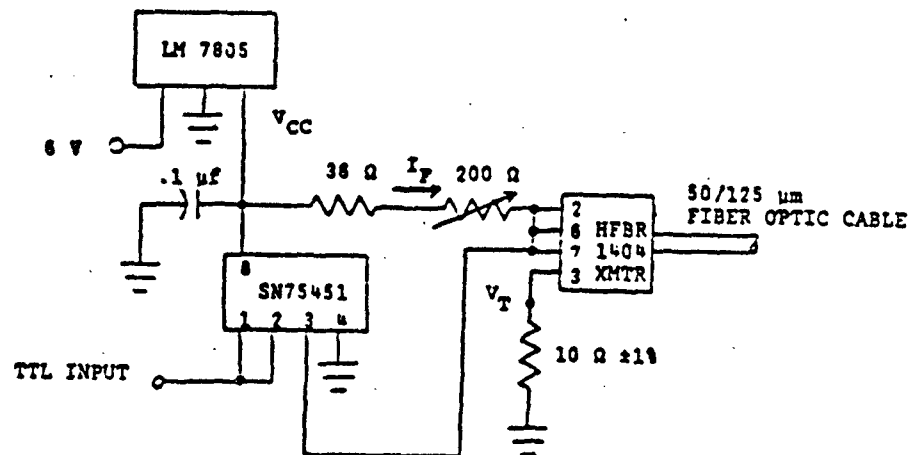


Figure 2.3 Transmitter Drive Circuit

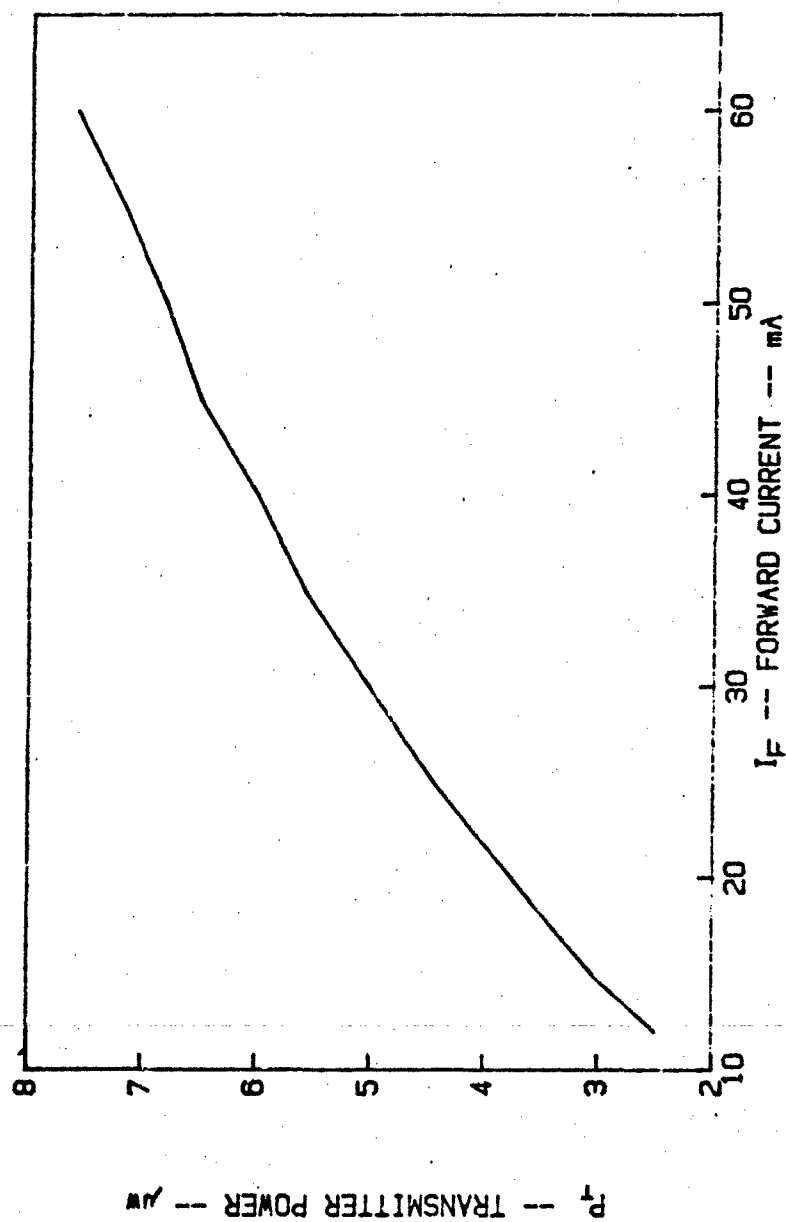


Figure 2.4 Transmitter Output vs. Forward Current

across the 10 ohm resistor,  $V_T$ , was measured with a digital volt meter as  $R_1$  was varied over the full range of the potentiometer. Additionally,  $I_F$  can be calculated from the following equation:

$$I_F = V_{CC} / ( R_1 + 36 + 10 ) \quad (2.6)$$

The 200 ohm potentiometer,  $R_1$ , allows  $I_F$  to be adjusted from 12 to 60 mA. The 36 ohm resistor was placed in series with  $R_1$  and the 10 ohm resistor to prevent  $I_F$  from exceeding the maximum rated forward drive current of 60 mA in the event that  $R_1$  was inadvertently zeroed while the circuit is energized.

The ability to control  $I_F$  provides the flexibility necessary to maximize circuit efficiency. The quantity  $I_{Fmin}$  is the minimum forward drive current required to produce a  $P_T$  sufficient for a positive system margin and yet minimizing the load on the 6-volt battery providing power to the transmitter drive circuit. The current  $I_{Fmin}$  for the seawater battery monitor was experimentally determined to be 43 mA.

## 2. HFBR-2402 Receiver

The Hewlett-Packard HFBR-2402 Fiber Optic Receiver is a low cost receiver capable of a 5 Mb/s data rate and  $10^{-9}$  BER at a minimum receiver power,  $P_R$ , of 4  $\mu$ W. The system margin is computed using Eq. 2.4; and for  $a_0 = 3.7$  dB/Km,  $L = 1.094$  Km,  $P_T = 17.78$   $\mu$ W and  $P_R = 4.0$   $\mu$ W, the

system margin is 2.66 dB. The positive system margin of 2.68 dB ensures that the receiver power,  $P_R$ , is greater than the minimum 4  $\mu$ W required. Therefore, the data rate and BER for the system application are more than adequate.

The HFBR-2402 is TTL compatible and designed to operate with various fibers terminated with SMA connectors. Consistent coupling is assured by a lensed optical system and response does not vary with fiber size.

The HFBR-2402 receiver is also housed in a low cost dual-in-line package and physically is identical to the HFBR-1404 with the one exception that the optical port of the HFBR-2402 is dark gray while the HFBR-1404 is light gray.

Figure 2.5 is the HFBR-2402 receiver circuit. A 560 ohm pull-up resistor is connected to the open-collector "data" output (pin 6) to provide a standard TTL signal to the frequency-to-voltage circuit.

#### C. FREQUENCY TO VOLTAGE CONVERTER (F/V CONVERTER)

The F/V converter converts the TTL "data" signal from the HFBR-2402 fiber optic receiver to an analog voltage. The F/V converter circuit is shown in Figure 2.6. The output voltage,  $V_{OUT}$ , is related to the frequency of the TTL input,  $f_{IN}$ , by:

$$V_{OUT} = f_{IN} (2.09 V_S) (R_L/R_S) R_t C_t \quad (2.7)$$

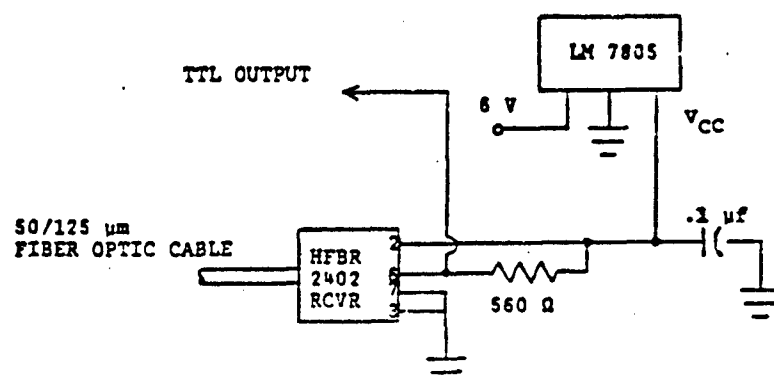


Figure 2.5 Receiver Drive Circuit

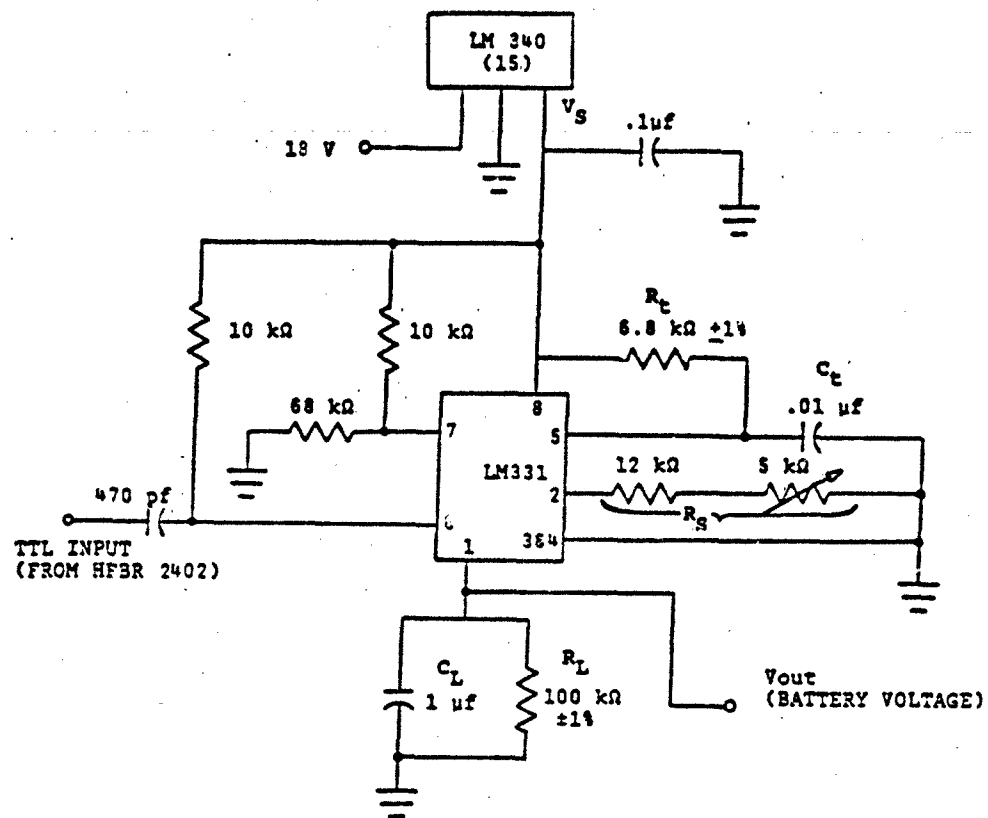


Figure 2.6 F/V Converter

The output voltage exhibits the same linear dependence on input signal frequency as seen with the V/F converter. As the input frequency changes from 1 to 10 KHz,  $V_{OUT}$  varies from 1 to 10 volts.

The effect of the prescaler used in the V/F converter results in a  $V_{OUT}$  that is ten times the original  $V_{IN}$ . The relationship between  $V_{IN}$  and  $V_{OUT}$  is:

$$V_{OUT} = 10 V_{IN} \quad (2.8)$$

Again, compensation for the gain introduced by the prescaler in the V/F converter is made in the data recording routine.

As with the V/F converter, the 5000 ohm potentiometer provides the tuning capability to achieve a one-to-one conversion from frequency to voltage, i.e., a 5 KHz input produces a 5 volt output. And as with the V/F converter, the potentiometer enables the system to be calibrated to produce an output equivalent to a known voltage input prior to deploying the system.

#### D. POWER SUPPLIES

Power requirements for the seawater battery recording system include 6 and 18 volts for the V/F and F/V converters and 6 volts for the fiber optic transmitter and receiver. Power for the shore-based F/V converter and receiver was supplied by regulated dc power supplies. For

the optic transmitter and V/F converter, power was supplied from rechargeable Nickel-Cadmium (Ni-Cad) batteries. A 12 volt and 6 volt battery were connected in series to provide 18 volts and a third single battery supplied the 6 volt source. Throughout system design and testing the Ni-Cad batteries used as test batteries and power sources were recharged using a constant current charging procedure contained in Appendix A [Ref. 4].

Since individual system circuits required either 5 or 15 volts, voltage regulators were used to provide the required voltages from the 6 and 18 volt sources. The voltage regulators selected were the LM7805 (5V) and LM341T (15V) positive voltage regulators. Each regulator provided a nominal 5 or 15 volts. Small fluctuations in supply voltages does not affect system operation. Tests indicated that system performance was unaffected as long as the 5 volt supply,  $V_{CC}$ , remained above 4.4 volts and the 15 volt supply,  $V_S$ , exceeded 12.5 volts.

Once deployed, the life of the battery monitoring system is entirely dependent on the useful life of the 6 and 18 volt batteries. To estimate the expected life of the system, measurements were made to determine current requirements (Table 2.4). The major source of power consumption is the transmitter forward drive current,  $I_{FMIN} = 43$  mA. The forward drive current and the load resulting from the pull-up resistor in the V/F converter

combine to limit the effective system life. Results indicate that the system can be expected to operate continuously for approximately 120 hours with single batteries. Longer lifetimes can be achieved by adding more batteries.

TABLE 2.4

ESTIMATED BATTERY LIFE

Battery	6 V	12 V
Amp Hr. Rating	8.0 hr	6.5 hr
Current Requirement	66 mA	14 mA
Effective Life (est.)	120 hr	464 hr

E. DATA RECORDING SYSTEM

In order to analyze the telemetry data from the seawater battery, a recording system was designed to provide a programmable periodic recording capability. Additionally, the recording system was designed to detect the rate of change in the data signal and to increase or decrease the periodic sample interval automatically if the change in the data signal exceeded program specified limits.

The data recording system as designed, consists of a Hewlett-Packard 3430A Multimeter, a Hewlett-Packard HP-85

microcomputer, a Hewlett-Packard HP 7470 Graphics Plotter, and the computer program developed to control data acquisition and recording. Figure 2.7 is a block diagram representation of the data recording system.

#### 1. HP-85 Microcomputer

The HP-85 personal computer enhanced by the addition of input/output, mass storage, and advanced programming memory chips (ROM) was chosen as the controller for the data recording system. The HP-85 microcomputer is a multipurpose computing device which uses an enhanced version of the BASIC programming language. This microcomputer has an internal printer, tape drive and three separate timers which can be programmed to generate periodic interrupts at specified intervals. These characteristics, as well as the small physical size and light weight, made the HP-85 well suited as the controller for the data recording system.

The HP-85 was connected to the HP 3490A multimeter via the Hewlett-Packard Instrument Bus (HPIB). The HPIB allows the system controller to communicate programmed command controls to the HP-3490A multimeter.

#### 2. HP 3490A Multimeter

The HP 3490A multimeter makes ac voltage, dc voltage, and resistance measurements with five digit resolution. Via the HPIB, the multimeter can be remotely programmed to provide data output, sample-and-hold

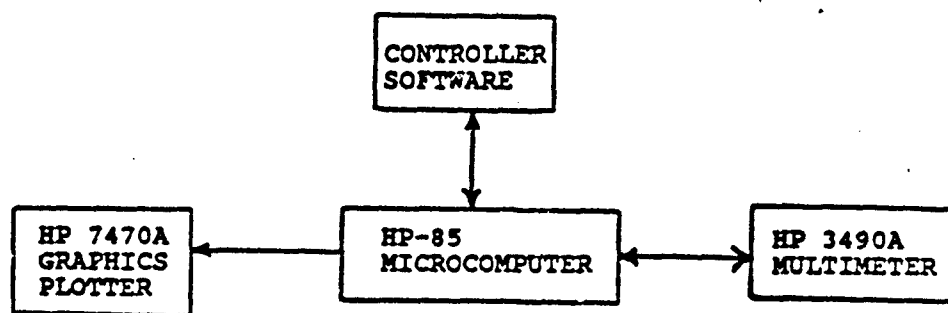


Figure 2.7 Data Recording System

measurements and ratio measurements. The remote program codes are contained in Appendix B [Ref. 5].

### 3. HP 7470A Graphics Plotter

The HP 7470A graphics plotter was used to plot the recorded battery telemetry data to provide a graphic representation of the degeneration characteristics of the monitored battery. All plots included in this thesis were made using the HP 7470A graphics plotter and a Superplotter plotting routine [Ref. 6].

### 4. Data Recording Programs

The computer program developed to control the recording system was written in an enhanced version of the BASIC programming language compatible with the HP-85 microcomputer. Appendix C is a listing of the data recording program.

As previously discussed, due to prescaling in the V/F converter, the voltage seen by the HP 3490A multimeter will be ten times the actual voltage of the battery being monitored. The data recording program scales down the periodic voltage readings by a factor of ten before the data is recorded on tape. Thus, the data recorded is a history of the actual voltage of the monitored battery.

The data recording program is interactive and enables the operator to specify three specific recording intervals. Each interval may be any value between 0.5 and 99,999,999 milliseconds. Once the program is initiated,

the operator is requested to input the initial battery voltage. This value will be the voltage currently displayed by the HP 3490A multimeter. Next, the operator is requested to input the largest desired sample interval, the next smaller sample interval and finally the smallest desired sample interval; all intervals may be chosen to be equal if desired.

The data recording system is now initialized and will proceed to periodically record the battery voltage at the specified largest sample interval. If a recorded voltage level decreases by more than ten percent of the previous recorded value, the recorder automatically shifts to the next smaller recording interval. Once at the next smaller recording interval recording will continue until either:

1. A voltage level recorded decreases by more than ten percent of the previous value; the recorder shifts to the smallest specified recording interval.
2. A voltage level recorded decreases by less than five percent of the previous value; the recorder shifts back to the largest recording interval.
3. The voltage of the battery being monitored falls below 0.1 volt; data recording is terminated.
4. The data record exceeds 500 entries; data recording is terminated.

If the system is operating at the "smallest recording interval", a shift back to the next larger recording interval will occur if the voltage level recorded decreases less than five percent of the previous recorded value. At

recording termination, the number of data points recorded and the elapsed recording time are output to the HP-85 printer.

The data recorded is stored on tape in a "random" data file. The random data file allows specific data entries to be retrieved from the data record. The random data file is especially desirable in the event that a large amount of data was recorded and only a small block of data is determined to be of interest.

Once the battery telemetry has been recorded on tape, the next step is to graphically display the data. To decrease the time required to execute the Superplot plotting routine, a conversion program was written to convert the tape data file to a floppy disk file. Appendix D is a listing of the program written to transfer the data to disk. Additionally, the random data file is transformed to a "sequential" data file prefaced with necessary commands to make the data file compatible with the Superplot plotting routine.

It should be noted that the Superplot routine as written will accept a maximum of 150 data points. Should the data file recorded on tape exceed 150 data entries, the number of data points transferred to disk can be controlled by simple modifications to the data conversion program.

#### F. ENVIRONMENTAL ENCLOSURES

Three saltwaterproof enclosures were used to house the "wet end" of the seawater battery monitoring system. The containers were of two types. The fiber optic transmitter and the test battery were mounted in enclosures as shown in Figure 2.8a. These containers were previously used in tests conducted on another fiber optic dat link [Ref. 7].

The enclosures were manufactured from PVC pipe with an inside diameter of 15 cm (6 inches). The removable endcap of the container housing the optic transmitter was fitted with a vent plug and two Brantner connectors to accept data and power inputs from the power supply and test battery containers. The fixed endcap was fitted with a penetrator to accept the fiber optic cable. The container housing the test battery was fitted with a single Brantner fitting.

Figure 2.8b is the container used to house the 6-volt and 18-volt batteries which provided power to the optic transmitter and V/F converter. The container was manufactured from PVC pipe with an inside diameter of 19 cm (7.5 inches). The removable flange, held in place by eight 3 1/2 x 5/16 in. bolts, was fitted with a single Brantner connector.

The three containers were connected by two 5 meter, six wire cables. The cables mated to the Brantner connectors of the environmental containers provided data and power to the fiber optic transmitter.

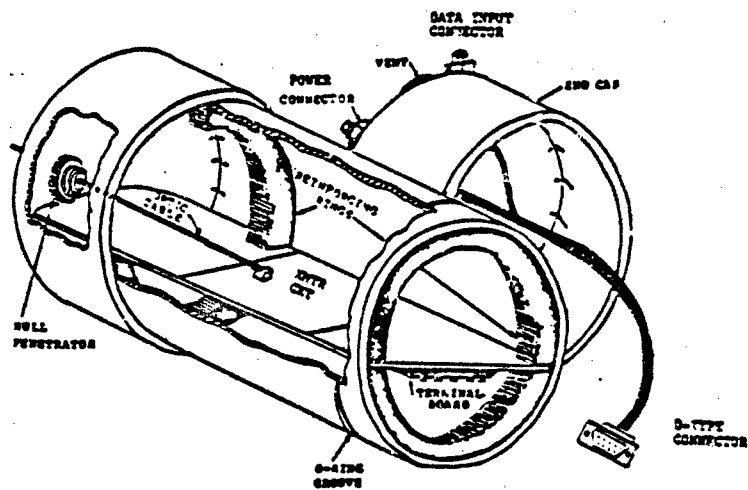


Figure 2.8a Transmitter Enclosure (after Ref. 7)

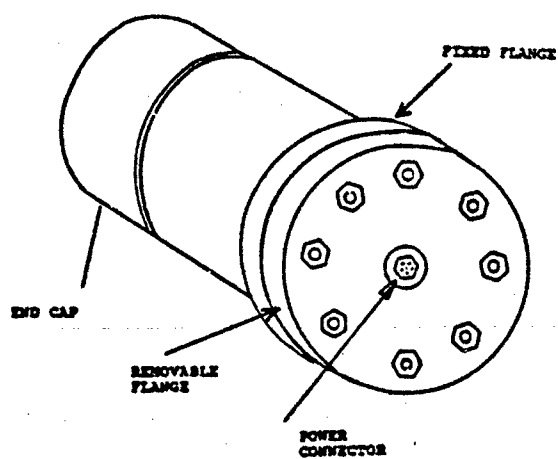


Figure 2.8b Power Supply Enclosure

### III. TEST AND EVALUATION

The individual circuit elements of the seawater battery monitoring system were integrated in hardware to form the complete system. Figure 2.9 illustrates how the V/F converter, optic transmitter, optic receiver, and F/V converter are interconnected to accomplish the transfer of battery information from the ocean deployed battery to a shore based receiver.

Test and evaluation of the complete system was accomplished in two phases. Prior to deploying the system in environmental containers, several tests were performed in the laboratory. The laboratory tests were conducted utilizing the same system elements that would ultimately be deployed in a seawater environment. In order to provide a measure of accuracy of system performance, an additional multimeter with the HP-IB capability was connected to the monitored battery. For each case investigated, simultaneous input and output voltage measurements were made.

Since the proposed seawater battery was not available at the time of testing, various other batteries were discharged and monitored over the effective life of the battery. To simulate the 1 volt seawater battery, a simple voltage divider, Figure 2.10, was implemented to act as a

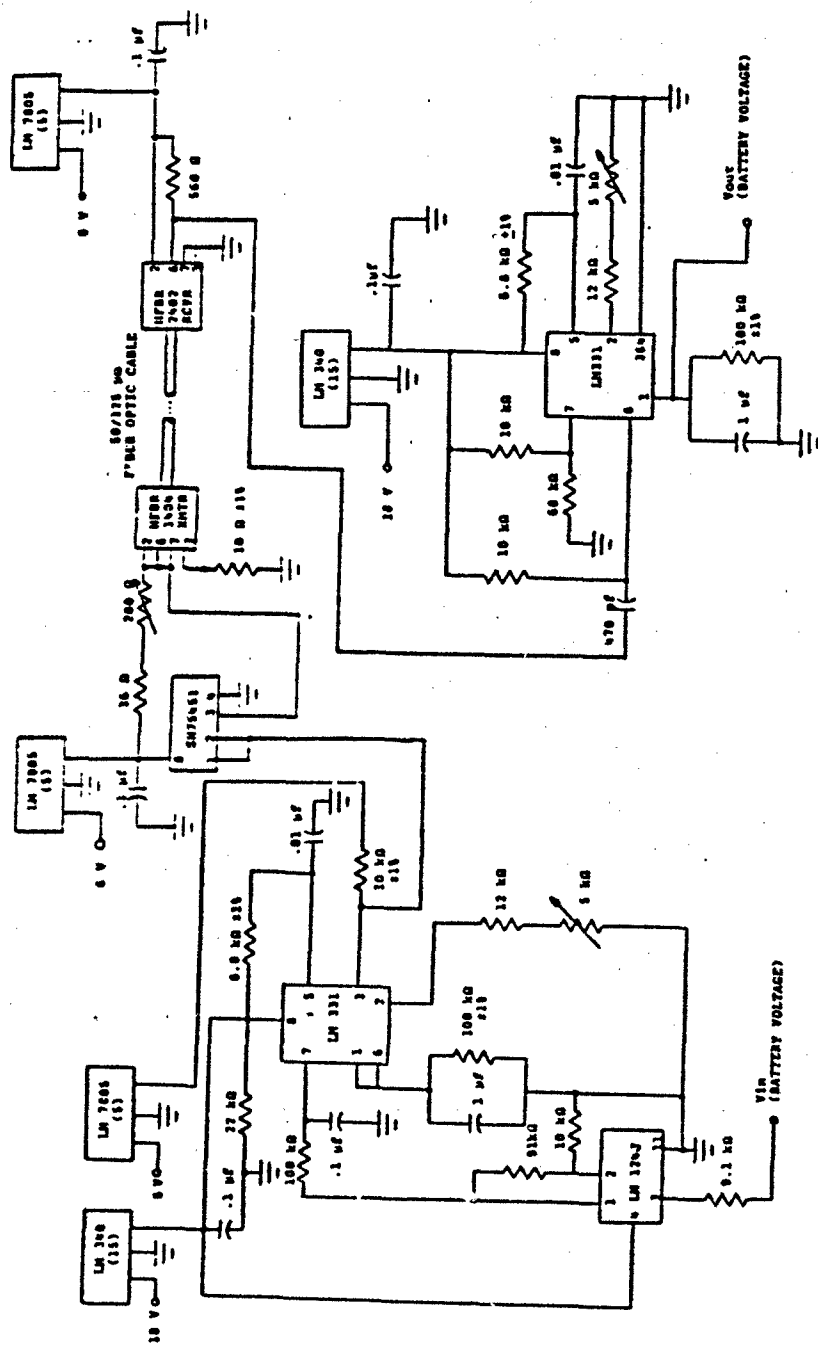


Figure 2.9 Data Link Circuit

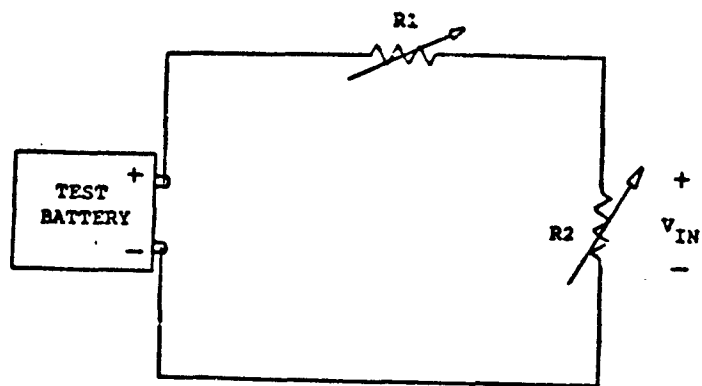


Figure 2.10 Voltage Divider Circuit

load and provide a 1-0 volt signal,  $V_{IN}$ , over the life of the test battery.

Figures 2.11 through 2.13 are results obtained from tests conducted on three separate batteries. In each case, the seawater battery monitoring system accurately transmitted and recorded the test battery voltage. For all batteries tested, system error ranged from zero at the beginning of the recording to a maximum error of less than five percent prior to recording termination.

The "final" system test incorporated the environmental enclosures and tested the total system in a seawater environment. The system was deployed from Monterey harbor Wharf 2, Monterey, CA. Figure 2.14 depicts the system as deployed. The test conducted was 3.5 hours in duration and Figure 2.15 is a plot of the battery telemetry information recorded.

Subsequent to the testing, an inspection of the opened containers revealed the containers of the type in Figure 2.8a showed no evidence of leakage. The container housing the battery power supplies showed signs of minimal leakage. Failure to properly seal the flange gasket was the suspected reason for the small amount of leakage experienced.

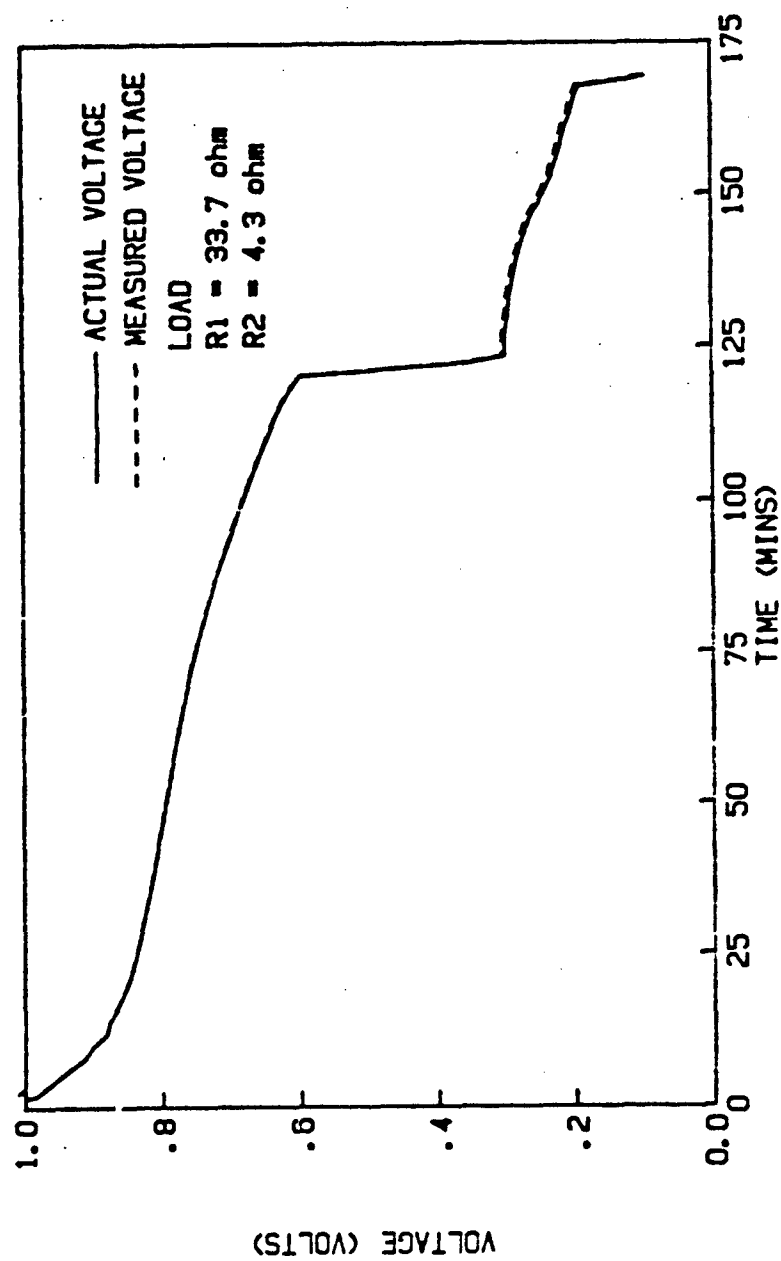


Figure 2.11 9 Volt Alkaline Battery  
Degeneration Characteristics

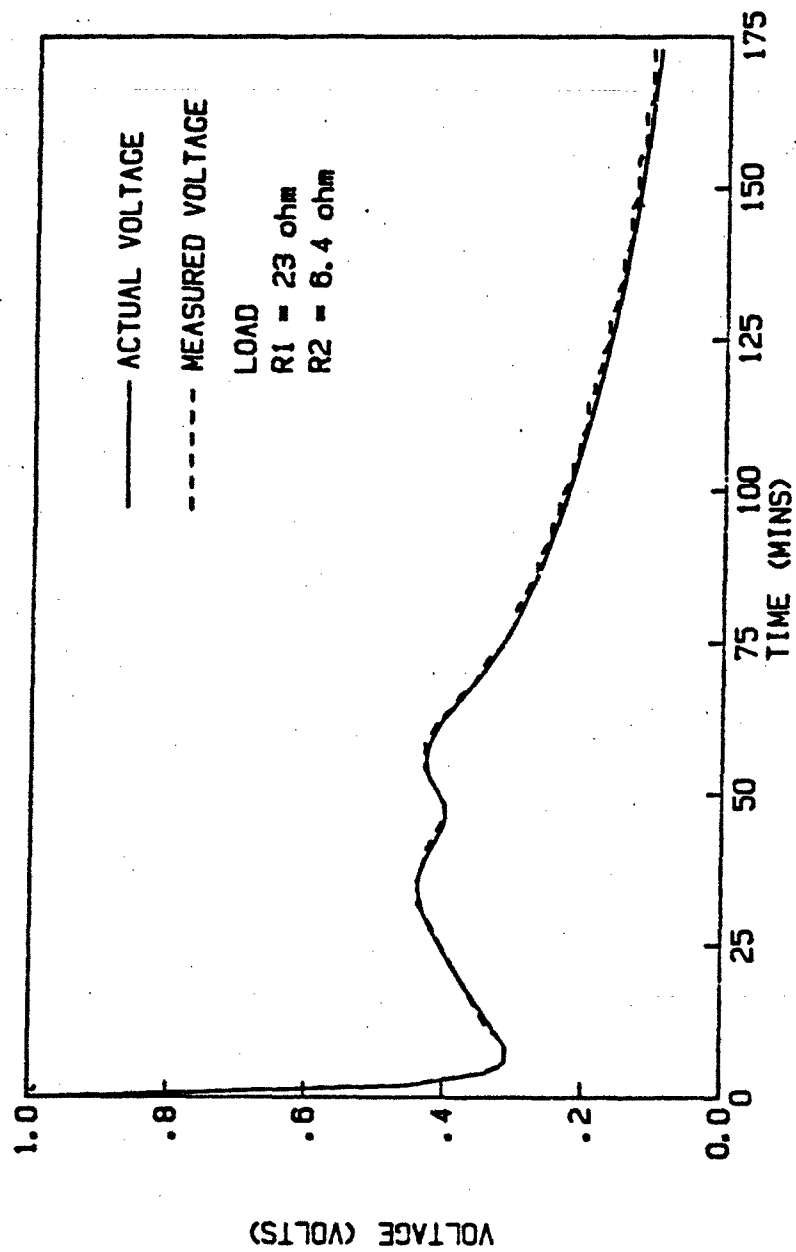


Figure 2.12 9 Volt Lead Acid Battery  
Degeneration Characteristics

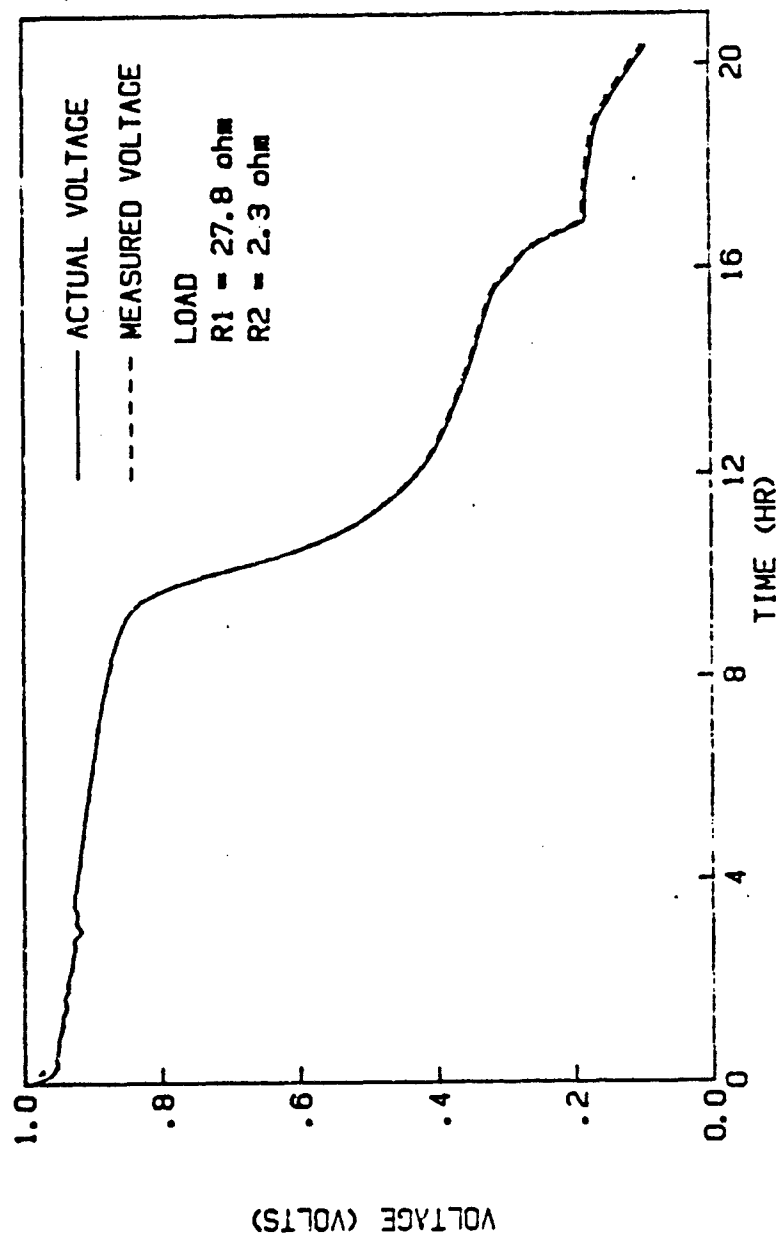


Figure 2.13 12 Volt Nickel-Cadmium Battery  
Degeneration Characteristics

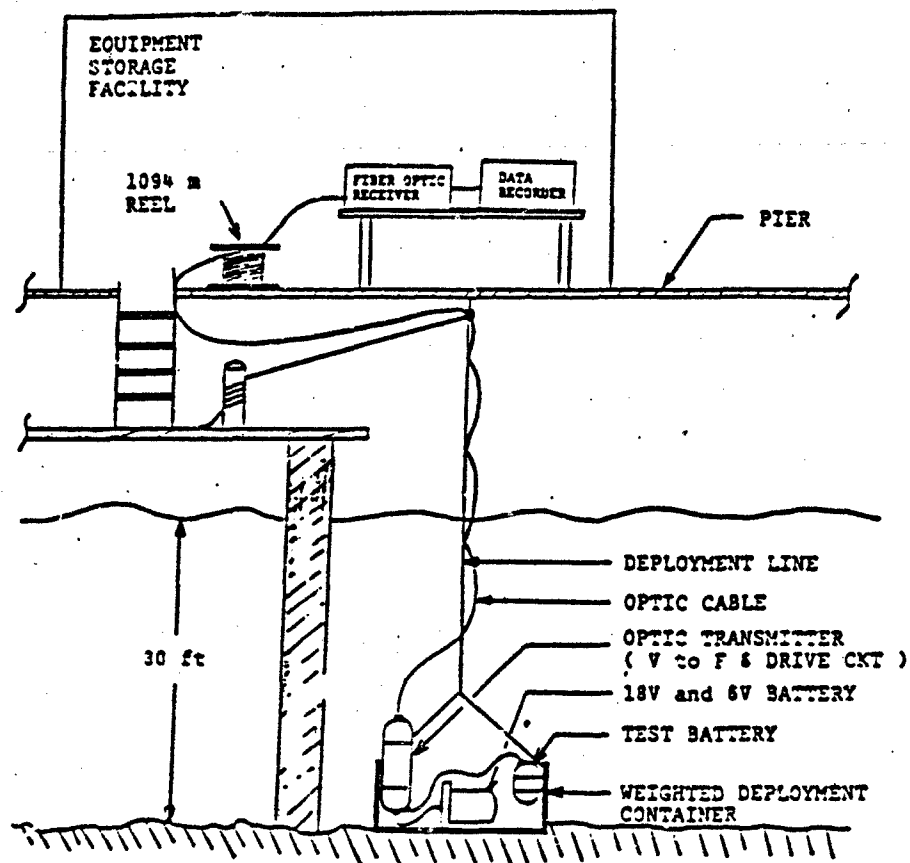


Figure 2.14 Deployed System

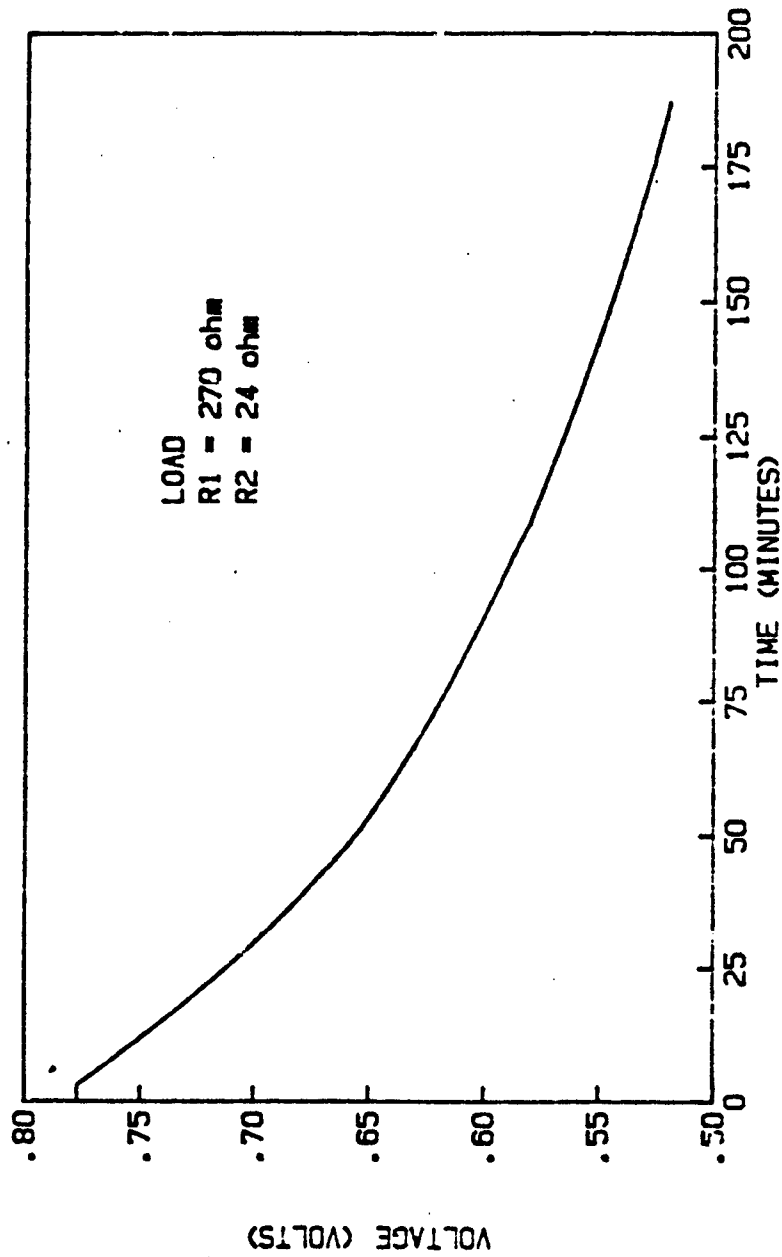


Figure 2.15 System "Wet Test" Results  
(6 Volt Nickel-Cadmium Battery  
Degeneration Characteristics)

#### IV. CONCLUSIONS AND RECOMMENDATIONS

The seawater battery recording system as designed, built, and deployed successfully met all the established design criteria. The system provides an effective low cost means of remotely monitoring a 1 volt seawater battery at distances up to 1 kilometer from shore. Although only tested to 1 kilometer, the calculated system margin of 2.68 dB indicates data transmission distances of 1.5 kilometers should be expected. If transmission distances greater than 1.5 kilometers were desired the transmitter and receiver could be replaced with suitable laser diode components or data repeaters could be implemented.

The maximum error experienced was less than 5 percent and could be reduced to less than 2.5 percent by calibrating the system for a midscale voltage vice the initial voltage. Specifically the system should be calibrated to output 5 volts for a 0.5 volt input. Midscale calibration would result in the maximum error occurring at the beginning and end of the battery life.

As written, the controller program does not provide a convenient method for gaining access to recorded data while recording is in progress. The ability to "pause" program operation, retrieve previously recorded data, display and

plot the data, and resume recording would be desirable for extremely long events.

The major limitation of the seawater battery recording system is the relatively short effective system life. The expected life of the seawater battery is estimated to be one year. In order to provide continuous monitoring a method should be developed to provide uninterrupted power to the V/F converter and the optic transmitter. Two possible solutions are proposed. A fiber optic cable with a conductor could be used to provide 17 volts to the LM7805 and LM341T voltage regulators. Another possible solution would be to tether long life power supply batteries near the deployed optic transmitter. A means would need to be devised to periodically replace the batteries without interrupting power to the V/F converter and optic transmitter.

## APPENDIX A

### CONSTANT CHARGING PROCEDURE [REF. 4]

The automatic crossover between constant voltage and constant current exhibited by most Hewlett-Packard power supplies make them ideal for battery recharging applications. The "constant current" method typically requires 14-16 hours to fully charge a nickel-cadmium (Ni-Cad) cell. The charge rate for this method is typically  $0.1C$ , where  $C$  is the nominal ampere-hour rating of the cell. The procedure for setting the charging rate and full charge voltage on constant voltage/constant current power supplies is as follows:

1. Turn both the VOLTAGE and CURRENT controls fully counterclockwise (CCW).
2. Place a short circuit across the output terminals of the supply and rotate the VOLTAGE control fully clockwise (CW).
3. Rotate the CURRENT control to the desired charging rate as read on the front panel ammeter.
4. Rotate the VOLTAGE control fully CCW and remove the short circuit.
5. Rotate the VOLTAGE control to the desired full charge voltage as read on either the front panel voltmeter or a more precise DVM. Remember to set the voltage 0.7 volts more than the required full charge voltage to compensate for the drop across diode CRp (Figure A.1).

The unit may then be connected to the battery terminals (positive to positive and negative to negative).

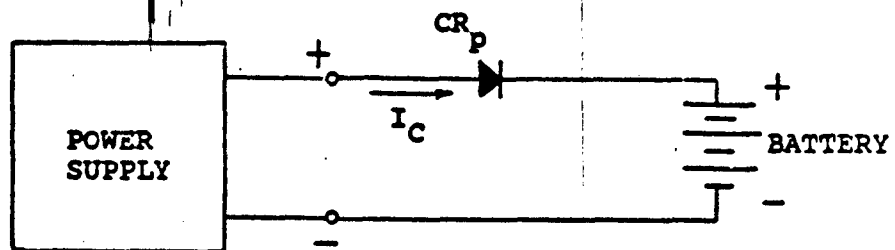


Figure A.1 Constant Current Charging

**APPENDIX B**  
**PROGRAM CODES [REF. 5]**

The following program codes enable the operator to  
program the HP 3490A multimeter for remote operation.

CHARACTER	USE	OCTAL CODE
R	Range Program Identifier	122
1	10,000 k $\Omega$ : Test 7	061
2	1,000 k $\Omega$ : 1000 V: Test 6	062
3	100 k $\Omega$ : 100 V: Test 5	063
4	10 k $\Omega$ : 10 V: Test 4	064
5	1 k $\Omega$ : 1 V: Test 3	065
6	.1 k $\Omega$ : .1 V: Test 2	066
7	Autorange: Test 1	067
F	Function Program Identifier	106
0	DC Volts	060
1	K Ohms	061
2	AC Volts	062
3	Test	063
S	Sample/Hold Program Identifier	123
0	Sample/Hold Off	060
1	Sample/Hold Off	061
2	Track/Hold	062
3	Acquire/Hold	063
T	Trigger Source Program Identifier	124
0	Internal Sample Rate *	060
1	Immediate Internal	061
2	Next External Trigger	062
3	None	063
M	Mode of Operation Program Identifier	115
0	Addressed Multi with No Output	060
1	Addressed Multi with Output	061
2	Addressed Single with No Output	062
3	Addressed Single with Output	063
4	Interrupt Multi with No Output	064
5	Interrupt Multi with Output	065
6	Interrupt Single with No Output	066
7	Interrupt Single with Output	067
E	Execute Mode of Operation Program	105

## APPENDIX C

### CONTROLLER PROGRAM

The controller program controls the operation of the seawater battery monitoring system. The program is interactive and enables the operator to specify the desired recording intervals. The program will cause the battery voltage to be periodically recorded on tape and will terminate recording when the battery voltage drops below 0.1 volt.

```
10  ! THIS PROGRAM WILL PERIODICALLY RECORD DC VOLTAGES
    ! FROM A HP 3490A MULTIMETER.
20  ! THE RECORDING INTERVALS MUST BE SPECIFIED IN THE
    ! DESIRED NUMBER OF MSEC (.5 TO 99999999)
30  ! THE PROGRAM IS INTERACTIVE AND ONCE INITIATED WILL
    ! CONTINUE TO RUN UNTIL THE INPUT
40  ! VOLTAGE DROPS BELOW 1 VOLT. THE VALUES RECORDED WILL
    ! BE SCALED DOWN TO ONE TENTH OF THE
50  ! INPUT VOLTAGE. THE DATA GENERATED IS STORED IN A
    ! RANDOM DATA FILE. AS WRITTEN, THE DATA
60  ! WILL BE RECORDED TO TAPE. THE PROGRAM MAY BE EASILY
    ! MODIFIED TO UTILIZE FLOPPY DISK
70  ! STORAGE IF THE FLOPPY DISK DRIVE IS AVAILABLE.
80  !
90  !
100 ON KEY# 1,"HALT" GOTO 110
110 CLEAR ! CLEARS DISPLAY
120 CREATE "WETOUT:T",500,40 ! CREATES INPUT DATA FILE
130 ASSIGN# 3 TO "WETOUT:T" ! OPEN INPUT DATA FILE
140 OUTPUT 722 ;"R4F0S0T0M1E" ! REMOTE CMD FOR 3490A
    MULTIMETER
150 DISP "ENTER INITIAL VOLTAGE" ! FROM 3490A
160 ! V2 = OUTPUT VOLTAGE
170 INPUT V
180 DISP "ENTER LARGEST SAMPLE INTERVAL"
190 INPUT R
200 DISP "ENTER NEXT SMALLER INTERVAL"
210 INPUT A
```

```

220 DISP "ENTER SMALLEST SAMPLE INTFRVAL"
230 INPUT Y
240 V0=V/10 ! CORRECTS FOR PRESCALE IN V/F CONVERTER
250 SETTIME 0,0 ! INITIALIZES CLOCK
260 T=TIME/60 ! TIME IN MINUTES
270 !
280 ! THIS PORTION OF THE PROGRAM USES TIMER #1 TO
    RECORD VOLTAGES AT THE "LARGEST SAMPLE INT"
290 !
300 PRINT
310 T1=T
320 ENTER 722 ; V
330 V1=V/10 ! CORRECTS FOR PRESCALE
340 PRINT# 3,1 ; T,V1
350 I=2
360 OFF TIMER# 2
370 WAIT R
380 ENTER 722 ; V
390 V1=V/10
400 PRINT V1
410 T=TIME/60
420 PRINT# 3,I ; T,V1
430 IF V1<.1 THEN 940
440 I=I+1
450 IF I=499 THEN 940
460 C1=.1*V0
470 X1=V0-V1
480 V0=V1
490 IF X1>C1 THEN 550
500 ON TIMER # 1,R GOTO 380
510 GOTC 510 ! WAIT LOOP
520 !
530 ! THIS PORTION OF THE PROGRAM USES TIMER #2 TO
    RECORD VOLTAGES OF "NEXT SMALLER SAMPLE INT"
540 !
550 OFF TIMER# 1
560 OFF TIMER# 2
570 WAIT A
580 ENTER 722 ; V
590 V1=V/10
600 PRINT V1
610 T=TIME/60
620 PRINT# 3,I ; T,V1
630 IF V1<.1 THEN 940
640 I=I+1
650 IF I=499 THEN 940
660 X2=V0-V1
670 C2=.05*V0

```

```

680 C3=.1*V0
690 V0=V/1
700 IF X2<C2 THEN 360
710 IF X2>C3 THEN 770
720 ON TIMER# 2,A GOTO 580
730 GOTO 730 ! WAIT LOOP
740 !
750 ! THIS PORTION OF THE PROGRAM USES TIMER #3 TO
    RECORD VOLTAGES AT THE "SMALLEST SAMPLE INT"
760 !
780 WAIT Y
790 ENTER 722 ; V
800 PRINT V1
810 V1=V/10
820 T=TIME/60
830 PRINT# 3,I ; T,V1
840 IF V1<.1 THEN 940
850 I=I+1
860 IF I=499 THEN 940
870 X3=V0-V
880 C4=.05*V0
890 V0=V
900 IF X3<C4 THEN 560
910 ON TIMER# 3,Y GOTO 790
920 GOTO 920 ! WAIT LOOP
930 ASSIGN# 3 TO *
940 OFF TIMER# 1
950 OFF TIMER# 2
960 OFF TIMER# 3
970 PRINT
980 PRINT
990 PRINT I,"DATA POINTS WERE RECORDED THIS SESSION"
1000 PRINT
1010 T2=T
1020 T9=T2-T1
1030 PRINT
1040 PRINT
1050 PRINT "TOTAL TIME ELAPSED FOR DATA RECORDING
    SESSION IS",T9,"MINUTES"
1060 STOP
1070 END

```

## APPENDIX D

### TAPE TO FLOPPY DISK CONVERSION PROGRAM

The tape to floppy disk conversion program converts a random data file with a known number of entries to a sequential data file. The first entry in the sequential data file is information required by the Superplot-3 plotting routine.

```
10  ! THIS PROGRAM GENERATES A SEQUENTIAL DATA
    ! FILE ON FLOPPY DISK FROM A RANDOM DATA FILE
20  ! STORED ON TAPE.  PROGRAM LINE 90 INITIALIZES
    ! THE DATA FILE
30  ! WITH INFORMATION REQUIRED BY THE SPLOT3 PLOTTING
    ! ROUTINE
40  !
50  !
60  CREATE "WETOUT:D700",500,40  !  CREATES FILE FOR DISK
70  ASSIGN# 2 TO  "WETOUT:T"
80  ASSIGN# 1 TO  "WETDAT:D700"
90  DISP "INPUT NUMBER OF DATA POINTS"
100 INPUT S
110 PRINT# 1 ; 1,0,S  ! REQUIRED FOR SPLOT3 PLOTTER ROUTINE
120 FOR I=1 TO S
130 READ# 2,I ; T,V
140 PRINT# 1 ; T,V
150 NEXT I
160 ASSIGN# 2 TO  *  !  CLOSSES DATA FILE
170 ASSIGN# 1 TO  *
180 DISP "CONVERSION OF RANDOM DATA FILE TO SERIAL DATA
    FILE COMPLETE"
190 DISP "END"
200 END
```

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